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RESEARCH MEMORANDUM

AN AIR-BORNE TARGET SIMULATOR FOR USE IN OPTICAL-SIGHT TRACKING STUDIES

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SUMMARY

The design and flight evaluation of an air-borne target simulator for use in tracking studies of fighter-type airplanes equipped with optical gunsights is described. Use of such equipment appeared to offer a number of advantages over the conventional techniques used in tracking research. The main purposes of the present investigation were to demonstrate principles and to obtain practical experience with mechanization and operation problems of a prototype simulator assembled from readily available components. The target airplane was represented by a movable dot of light projected on the windscreen of the test airplane. This dot was slaved to a gyro reference system representing the line of sight to the target. This simulated target dot was thus stabilized against oscillations of the tracking airplane, but could be driven at precomputed rates in space to represent selected target maneuvers.

Quantitative data and pilots' comments were obtained from a brief flight evaluation which involved comparable fixed gunsight tracking runs on a simulated target and an actual target airplane. The standard maneuver which was used included periods of steady straight flight, steady turning flight, and the transition period associated with the abrupt target turn entry. The results indicated that the optical target simulator would be a useful tool in tracking research. For certain applications, it might be desirable to add "wings" to the target display to provide the normally available warning of target turn and to improve slight stabilization deficiencies of the simulated target which caused a small increase in random tracking errors. Compared to conventional tracking research techniques, the target simulator eliminated the need for a second airplane and provided accurate repetition of selected attacks. Tracking-error data were successfully recorded in time-history form susceptible to rapid analysis by automatic data-reduction devices.

The experience with this prototype simulator suggested a number of other possible devices based on similar principles. These include a

target simulator for use with fire-control systems involving a tracking radar and scope presentation, and an air-launched missile simulator. In addition to being useful in research, these simulators might prove advantageous in weapons-system evaluation and in pilot training. Another application involves use of the windshield tracking display of the prototype simulator for a precision-instrument flight display.

INTRODUCTION

The Ames Aeronautical Laboratory has been engaged for several years in flight investigations of the effects of various airframe and optical-sight characteristics on the tracking performance of fighter-type airplanes (see, e.g., refs. 1 and 2). The flight-test procedure has been conventional with tracking errors evaluated from motion pictures taken with gunsight aiming point (GSAP) cameras during nonfiring tracking runs against target airplanes. Tracking performance must be expressed statistically, and careful, extensive flight tests and analysis are required in order to produce significant data for each combination of airplane, gunsight, and operating condition. When, as in the Ames research studies, many combinations of such variables are of interest, it is a formidable task to obtain and analyze the necessarily voluminous data in a reasonable time. The idea of an air-borne target simulator was first considered at Ames in 1952 and was recognized as a promising means of facilitating such research.

The Ames target simulator involves a gyro-stabilized reference axis in the tracking airplane which simulates the line of sight to an actual target airplane. The direction of this line of sight is reproduced optically by a dot on the windshield or on a tracking scope. Since the line of sight is stabilized against oscillations of the tracking aircraft, the dot can serve as a target airplane in straight tail-chase tracking. To simulate a maneuvering target, the line of sight reference axis, and hence the target dot, is programmed to turn in the same manner as the line of sight to an actual target. Use of such a simulated target not only eliminates the need for a second airplane to serve as a target, but also assures accurate repetition of selected attacks and permits recording tracking errors in time-history form suitable for rapid data reading and reduction.

It was decided first to construct and test a prototype air-borne optical (windshield presentation) target simulator which would demonstrate principles and would furnish experience with problems of mechanization and operation, many of them identical to those anticipated in the contemplated design of a target simulator for a scope-presentation fire-control system. No attempt was made in this prototype to simulate target aspect and range, but only the angular orientation of the target line of sight, the kinematic property essential in Ames optical-sight tracking research and in other possible applications of target-simulator principles.

The development of this air-borne optical target simulator and the results of evaluation flight tests (including a comparison of airplane tracking performance against the simulated and an actual target airplane) are presented herein.

NOTATION

$\angle GL$	angle between attacker airplane gunsight line and a fixed space axis
$\angle \dot{GL}$	angular turning rate of gunsight line
$\angle LS$	angle between attacker airplane line of sight to target and a fixed space axis
$\angle \dot{LS}$	angular turning rate of line of sight
HIGU	hermetic integrating gyro unit
σ_x	azimuth standard deviation, mils
σ_y	elevation standard deviation, mils
$\bar{x}$	azimuth average or bias error, mils
$\bar{y}$	elevation average or bias error, mils

DESCRIPTION OF APPARATUS

Target Simulator

Design principles.- In order to provide an understanding of the simplifications and limitations of the prototype simulator, let us first consider the information normally used by the pilot in tracking a target airplane and sketch a refined target simulator which would supply all of this information for any kind of attack. The various quantities involved in the optical tracking problem are indicated in figure 1(a). Information of possible use to the pilot in the tracking process includes range, orientation of the target line of sight both in space and with respect to the attacker fixed gunsight line or other attacker axis, and the target aspect or relative attitude, and various time derivatives of these quantities. Figure 1(b) is a generalized diagram of a hypothetical target simulator which furnishes all of this tracking information. The arrangement is much the same as that used in ground simulator setups of tracking or antiaircraft missile guidance problems. A course generator furnishes target space kinematic data pertaining to the selected target motions. Corresponding attacker kinematic data must be supplied by instruments in the airplane. These data are processed by a relative kinematics computer which yields signals representing the target range, aspect, and orientation. For optical gunsight tracking studies these data are converted into a pictorial display by some type of optical presentation device.

Detailed examination of a refined simulator of the type illustrated in figure 1(b) revealed a number of feasible but complicated methods for mechanization. However, consideration of the techniques and results of the previous Ames optical gunsight tracking research indicated that a less ambitious simulator of much simpler construction would be adequate for use in this tracking research. The technique used in these previous studies involves continuous tail-chase tracking of the target airplane at essentially constant range during straight flight and selected maneuvers. Results of previous brief tests indicated that for values of practical interest, range had little effect on pursuit tracking performance. Hence, no attempt was made to provide range information in the prototype simulator. In regard to target aspect, it was recognized that this information (particularly target banking motions) may be useful to the tracking pilot in anticipating target maneuvers. However, in general, target aspect data are of secondary importance compared to the line-of-sight orientation information which is of fundamental importance in all tracking problems. In fact, target-aspect information is not even available in the tracking-radar, scope-presentation fire-control systems for which eventual development of a target simulator was of interest. For the prototype optical target simulator, it was decided to avoid the target-aspect mechanization problem and to concentrate on the computation and presentation of only the line-of-sight orientation, which was of primary concern.

To consider the problem of simulating the target line-of-sight orientation, let us again refer to figure 1(a). The task of a pilot is to keep the gunsight line superimposed on the target line of sight; the angular separation between these two lines is the tracking error. If the pilot flies with no tracking error, the airplane flight path can be computed for a given target maneuver and given initial conditions. Hence, the rate of rotation of the line of sight can be calculated prior to flight. The ability to precompute this relative kinematics data is used in the prototype simulator to simplify establishment of the line-of-sight orientation. The general scheme is shown in figure 2. Time histories of line-of-sight rotation rates are precomputed for selected target maneuvers, with perfect tracking assumed. These data are stored in a relative kinematics programmer which supplies proportional electrical signals to a line-of-sight orientation reference. One axis of this gyro reference system represents the line of sight to the target. It is stabilized against own-ship oscillations but will rotate in space at rates exactly proportional to commands from the programmer. The measured orientation of the line-of-sight axis with respect to aircraft axes is reproduced by a "target" pip of light on the pilot's windshield. It is seen that, compared to the more refined simulator of figure 1(b), the use of a relative kinematics programmer replaces both the target course generator and the relative kinematics computer and simplifies considerably the attacker instruments.

Description of components.- A simplified diagram of one channel of the prototype target simulator is shown in figure 3. The basic subsystem is the modified radar-antenna drive system of an E-3 fire-control system which serves as the line-of-sight orientation reference. This radar-antenna drive system is readily adaptable to this purpose because in its normal use it is stabilized against aircraft pitch and yaw oscillations, and can be driven to follow a radar beam along the line of sight to a target. The following is a brief description of the antenna drive system as originally designed and as modified for the target simulator; more details on the E-3 system are given in reference 3.

The antenna is a paraboloidal reflector with a radiating dipole mounted along its axis of symmetry. A double-gimbal axis system carries the antenna with respect to the airplane about an outer azimuth axis and an inner elevation axis. Since radar is not used in the simulator, the antenna reflector and dipole were removed. In this report, the remaining antenna system consisting of gimbals, gimbal drive system, and gyros will be referred to simply as the antenna. The antenna dipole direction will be referred to as the direction of the antenna.

Two single-degree-of-freedom, hermetically sealed, integrating rate gyros (HIGU) are mounted with their rate-sensitive axes in the plane normal to the antenna direction and at right angles to each other. A detailed description of the HIGU is given in reference 4. Briefly, the outer case of an HIGU gyro supports an output shaft. A torque motor is mounted on one end of the shaft and a microsyn pickoff on the other. The middle of the shaft supports a spinning gyro wheel. The gyro wheel is enclosed in a hermetically sealed cylinder whose outer diameter is slightly smaller than the inner diameter of the case; the annular separation is filled with a viscous fluid.

When the case is rotated about an axis at right angles to the gyro spin axis, the gyro exerts a reaction torque about the axis perpendicular to both the angular input axis and the gyro spin axis. The torque about the output shaft is proportional to the component of the input angular velocity along a gyro unit sensitive axis perpendicular to the output shaft. The torque motor applies another torque to the output shaft proportional to an input signal current. If this input signal is made proportional to a desired turning rate about the gyro sensitive axis, the net torque on the output shaft is proportional to the algebraic difference between the actual and the desired turning rate. Rotation of the output shaft is opposed by the viscous fluid between the gyro cylinder and the outer case to provide an integrating action. The resultant motion of the output shaft, which is measured by the microsyn pickoff, is proportional to the time integral of the algebraic difference between the actual and the desired rates.

Use of the HIGU gyros in controlling the action of the antenna will be described in connection with figure 3 where only the azimuth channel is shown. An HIGU gyro is shown rigidly attached to the antenna which is driven with respect to the airplane by a drive motor. When the airplane yaws, the antenna rotates with it if the antenna drive motor is fixed. However, the airplane and the antenna can rotate independently, depending on the action of the motor.

With no signal current to the gyro torque motor, when the airplane yaws to the right, the antenna initially turns with it. This rotation is sensed by the HIGU, whose microsyn pickoff develops a voltage whose magnitude is proportional to the antenna rotation in space, and whose phase depends on the sense of the rotation. After amplification, this voltage is so applied to the drive motor that it rotates the antenna to the left at the proper speed to keep the antenna stationary in space as the airplane yaws. The gain of the system is sufficiently high that only a slight rotation of the gyro output shaft is required to actuate the drive motor. The integrating property of the gyro compensates for the small lag of the system and insures that the antenna will be driven through an angle of the same size and of opposite sense to that through which the airplane moves. In this way, the E-3 antenna is stabilized against aircraft oscillations. This space-stabilization feature of the antenna, whose direction represents the line of sight to the target, permits simulation of a nonmaneuvering target in straight tail-chase tracking, in which line-of-sight rotations in space are negligible.

When it is desired to simulate a maneuvering target, a current proportional to the precomputed line-of-sight rate for the selected target maneuver is applied to the gyro torque motor. The output of the HIGU is now proportional to the time integral of the algebraic difference between the actual and desired turning rates in space; that is, the difference between actual and desired antenna direction in space. This error signal from the HIGU microsyn pickoff is applied to the drive motor to rotate the antenna in the proper direction to null the error signal. Since the system gain is high, the error is always small and the integrating property of the HIGU insures that the antenna eventually rotates through the desired angle in space. In this way the HIGU gyros drive the E-3 antenna, which represents the line of sight to the target, at desired rates in inertial space independent of airplane rotations.

To program the desired line-of-sight rates, a constant speed motor turns a cam shaft at the rate of 1 revolution in 2 minutes. On the shaft are two hardened steel disc cams with a basic diameter of 4 inches. The edges are contoured to give follower motions proportional in magnitude and direction to the line-of-sight rates. The conversion of cam elevation to signal voltage is achieved by linearsyns whose lengthened shafts, each equipped with a steel roller tip, serve as cam followers. Smaller cams mounted on the cam shaft operate microswitches that shut off the program motor at a preselected time.

It was not considered advisable to precompute and program the line-of-sight rates directly in the banked antenna coordinates corresponding to the HIGU gyro sensitive axes. The difficulty is that although the tracking-airplane flight path and gross banking motion can be predicted for a selected attack, it is not possible to predict the additional sizable short-term variations in bank that often occur in flight. These short-term bank variations do not have appreciable effect on the airplane flight path or on the line-of-sight rates in unbanked coordinates. Accordingly, the program line-of-sight rates are precomputed in unbanked axes perpendicular to the line of sight. A roll gyro is mounted on the antenna to measure the bank of this coordinate system. The line-of-sight rate signals are transformed into the banked antenna coordinates by a resolver mounted on the gyro, amplified, and forwarded as commands to the appropriate HIGU gyros.

The sighthead of an A-1 armament control system was modified to provide the optical display to the pilot in the prototype target simulator. This sighthead contains a mirror whose position is controlled by the positions of two shafts. Rotating one or the other of the shafts rotates the mirror and deflects the light pip projected on the windshield (or, actually, on a combining glass) in either azimuth or elevation. In the target simulator, the system is used as a follow-up servo to aline the mirror shaft with the antenna. The motor turns until the shaft pickoff signal matches the line-of-sight orientation signal from the antenna pickoff, and the light pip, representing the target, makes the same angle with the gun line as the antenna. Since the A-1 lens system forms the image of a light pip at infinity, the pip orientation appears constant to a pilot if he moves his head inadvertently.

To give the pilot a fixed gunsight pip, a piece of clear glass with plane parallel sides and of good optical quality was inserted into the optical path between the collimating lens and the movable mirror of the sighthead (fig. 4(a)). The glass, acting as a beam splitter, reflects part of the incident light onto the cockpit combining glass to form the fixed pip. The transmitted light is reflected by the movable mirror. From the mirror this light passes through the beam splitter a second time, up through a cover glass which seals the sighthead, and onto the cockpit combining glass. The back of the beam splitter has an antireflection coating which reduces multiple reflections. The beam splitter lies as close to the mirror as possible and parallel to the mirror in its reference position. It has to be considerably larger than the mirror so as to reduce the field over which the pips are visible as little as possible. Set screws through the sighthead case are provided for alinement of the beam splitter.

To assist the pilot in differentiating between the two pips, use of a beam splitter of colored glass to give pips of different colors was investigated. However, this was abandoned because of parallax between the pips which can occur due to the inability of the simple A-1 collimating lens to focus the two pips of different colors at infinity simultaneously.

Installation in Test Airplane

Figure 5 shows the equipment compartment in the nose of the F80-A test airplane. The programmer, the E-3 antenna system, a recording galvanometer, and the electrical and electronic equipment associated with the operation of the target simulator are mounted as an easily removable single package. The package slides on aluminum channel bars into the airplane compartment and connects electrically with the remaining equipment by cables run to plug-in type connectors.

Figure 4(b) shows the equipment installed in the cockpit. A console beside the pilot contains the electric trim controls and switches necessary for the operation of the simulator and recording equipment. A trigger switch mounted on the pilot's control stick is used to start the programmer motor. The 16-mm GSAP camera and the A-1 sighthead are attached independently to the cockpit structure. A partially aluminized combining glass reflects the pip images to the pilot and the camera. Not shown is a pistol-grip type hand control for use when the system is in its "hand-control" mode. In this mode, programmer and HIGU are switched out of the antenna drive circuit and the antenna is slaved to the hand control. This feature permits the pilot to adjust the initial antenna position, which is still displayed by the target pip.

The target pip must be accurately adjusted parallel to the antenna in order to provide identical motions when the airplane rolls. This alinement was achieved by a simple boresight procedure. A permanent boresight mount attached to the airplane nose structure was adjusted to point 4° above the aircraft level line in the aircraft plane of symmetry. Another boresight mount was provided on the antenna. The antenna was alined with the nose reference direction by sighting the same distant object through boresights installed on these two mounts. The fixed pip in the A-1 sighthead was then centered on the same distant object by adjusting the set screws of the beam splitter. Finally, the target pip was alined with the fixed pip by adjusting the mirror microsyn pickoff, simultaneous mechanical and electrical alinement with the antenna thus being obtained, repeatable to 1 mil.

Instrumentation

The 16-mm camera shown in figure 4(b) recorded the pilot's display at seven frames per second. Sample movie frames during steady-turn tracking against a simulated and an actual target are shown in figure 6.

During simulated runs a standard miniature NACA nine-channel oscillograph recorded azimuth and elevation tracking error, programmed rate signals both before and after the resolver, and camera speed. Ektachrome color film was used in the oscillograph so that each trace is identifiable by its color. An example record is shown in figure 7.

TESTS AND RESULTS

Preliminary Tests

Ground tests.- After the simulator components were tested individually and together, it was desired to subject the simulator to the flight tracking situations, to the extent that these could be duplicated readily on the ground. The antenna and sighthead were mounted in the gimballed frame of a large searchlight which could be rotated by hand about all three axes. One GSAP camera was mounted on the antenna to establish the antenna direction by photographing landmarks of known location; another camera was mounted on the sighthead to view the landmarks and the light pip images simultaneously through the sighthead combining glass. To avoid parallax, it was necessary to perform the tests on a rooftop that commanded a view of relatively distant terrain.

Three types of tests were performed with the target simulator in the searchlight gimbal. First, the ability of the antenna and the target pip to follow severe line-of-sight rate commands with no base motion was checked by applying programmed signals while the searchlight gimbals were locked at various bank angles. The antenna response was satisfactory and the target pip followed the antenna closely. Next, the stabilization of the antenna and target pip against base motions in the absence of programmed commands was checked by oscillating the gimbal system by hand in azimuth and elevation. It was difficult to evaluate the stabilization quantitatively with the technique, due to the jerkiness of the base gimbals when oscillated by hand. However, the tests indicated that when the gimbal motion had the smoothness characteristic of airplane motions the stabilization was adequate. Finally, the ability of the antenna and target pip to follow space line-of-sight rate commands in the presence of base motions was checked by driving the antenna with the line-of-sight program while an operator tracked the target pip with the fixed pip by moving the base gimbals. The line-of-sight rate time histories and, once again, the jerkiness of the base gimbal motion were more severe than those expected in flight. The tests indicated that for the expected flight tracking problems and aircraft oscillations the performance of the target simulator would be adequate.

Flight tests.- To facilitate analysis of target-simulator performance, the time histories of the line-of-sight rate commands did not correspond to any particular tracking problem. Instead, line-of-sight motion patterns representative of various tracking problems were combined to form the test program shown in time-history form in figure 8. It is seen that the program rate pattern in the horizontal plane calls for alternate left and right turns separated by brief periods of steady straight (zero rate) flight. Steady turning rates of 0.07, 0.14, and 0.21 radian per second were included, with corresponding maximum angular accelerations of the line of sight of 0.037, 0.055, and 0.066 radian per second per second. In the vertical plane the pattern calls for alternate pull-ups and push-downs of rates of about 0.06 radian per second. The required maneuvers were synchronized with the horizontal rates. The pilot was furnished a switch for selecting either the horizontal or vertical program or both. No great difficulty was experienced in tracking the vertical program. The horizontal program could also be followed satisfactorily, but the pattern toward the end of the cam severely taxed the pilot and the airplane maneuvering capabilities. Numerous adjustments and minor changes were of course made to the target simulator during the flight program. This led to performance which, on the basis of pilot opinion and recorded data, was judged to be satisfactory for simulation of a target in a tracking run, and the work proceeded in this direction.

Gunnery-Run Evaluation

The preliminary flight tests demonstrated that the simulated target pip would satisfactorily duplicate line-of-sight motions representative of those encountered in various optical gunsight attacks against an actual target. In order to assess the usefulness and possible limitations of the target simulator as a research tool, tracking-error data and pilot's impressions from fixed gunsight tracking runs made with the test airplane against an actual target airplane were compared with those from tracking runs against a simulated target for the same attack situations and target maneuvers. The test and data-reduction techniques are described and the results are presented in the following section.

Test procedure.- The tracking problem used in these flights was the standard gunnery run used in previous Ames research (ref. 2). As shown by the plan view of figure 9, the attacker pursues a target airplane which first flies straight and level for about 27 seconds. The target then banks abruptly to enter a turn which is maintained for about 30 seconds at constant normal acceleration, essentially in the horizontal plane. During the entire period the attacking pilot attempts to track the target with the fixed gunsight. The nominal flight conditions for the present tests were a Mach number of 0.5, an altitude of 15,000 feet, and a range of 1,000 feet. All target turns were made to the left and without warning to the tracking pilot. Steady turns of both 2 and 3g normal acceleration were used in the test.

In initial tracking runs against the actual TV-1 target airplane with the fixed gunsight alined with the aircraft level line, the tracking airplane was disturbed considerably by the turbulent wake from the target, particularly during turning flight. To obtain data comparable to that from the simulated tracking runs where no such wake exists, the gunsight line was elevated 4° above the aircraft level line for all test flights against both actual and simulated targets.

Figure 10 shows the time histories of the line-of-sight rates programmed in the simulated gunnery runs. Because the Ames standard gunnery run maneuver lies essentially in the horizontal plane, it was not necessary to program any vertical-line-of-sight rates. Instead, the "vertical" cam was used to store an additional horizontal-rate program. Figure 10(a) shows the time histories corresponding to a 2g maneuver, which is stored on one cam; and figure 10(b) shows the time histories corresponding to a 3g maneuver, which is stored on the other cam. On each cam are two runs, one with a right turn, the other with a left turn at the same rate. The shape of these curves was determined by a calculation based purely on the geometry of pursuit in a steady turn for the selected nominal flight-test conditions. It was recognized that, due to variations in such quantities as range, air speed, and abruptness of target turn entry, the flight line-of-sight rate time histories would differ from these computed rates. Accordingly, an attempt was made to measure line-of-sight rate data in tracking runs against an actual target for possible use in the simulator. Unfortunately, the lateral and longitudinal oscillations of the tracking aircraft prevented fairing smooth time histories of principal interest, particularly in the critical region of turn entry. However, as indicated in figure 11, they were useful for monitoring the simplified computations. Here the computed line-of-sight rate time history for the initial portion of the 3g target turn maneuver is shown in comparison with the region which includes the recorded data from a number of similar maneuvers with an actual target. Incidentally, it was found that the measured line-of-sight rate time histories were very sensitive to range rate which, although usually small, appeared to account in large part for the width of the shaded region in figure 11.

For tracking runs against a simulated target, the pilot could select either the 2g or 3g cam. By changing this selector switch at the end of each run, the pilot could obtain a set of runs with the turns in the same direction, alternately of 2 and 3g's. To initiate a run, the pilot selects a program and flies straight and level. By means of the hand control, he alines the target pip with the fixed gunsight pip. After he releases a trigger on the hand control, the system is in its "program" mode and the line of sight is stabilized. He then presses a switch on the control stick to start the program cam, and tracks continuously to the end of a run signified by the steep ramps in the curves of figure 10. Here the antenna is driven quickly to a mechanical limit where it trips a switch which changes the operation mode from "program" to "hand control." The antenna then automatically returns to a center position and the program motor is turned off, in preparation for another run.

Data reduction and results.- Tracking errors against the actual target airplane were evaluated from GSAP film such as shown in figure 6. Telereader film evaluation equipment was used to evaluate azimuth and elevation components of tracking error, measured in a Cartesian coordinate system fixed to the airplane and centered at the gunsight pip. Each movie frame was read, giving about seven readings per second, corresponding to the reduced GSAP camera speed used in these tests.

Tracking errors against the simulated target were read directly from the oscillograph film as illustrated in figure 7. Conventional telereader equipment and procedures were employed to obtain the tracking errors from the continuous oscillograph traces. The tracking errors were also evaluated from GSAP camera film for comparison with the oscillograph data. In general, the agreement was satisfactory. In particular, the agreement was excellent insofar as the statistical quantities used in defining and summarizing tracking performance was concerned.

As in previous Ames tracking research (ref. 2), the data were divided into three parts for analysis, corresponding to three phases of the standard gunnery run. The first part begins as the run begins, and continues throughout the 27 seconds of straight and level flight until the target begins to turn. The beginning of the turn marks the start of the second portion of flight, termed the "transition region," in which the attacker airplane is changing from steady straight flight to approximately steady turning flight. The third phase corresponds to the target steady turn during which the attacker also turns at essentially constant rate. In selecting the transition region, there was no difficulty in determining the point at which the target turn began. In the runs against an actual target airplane, the GSAP pictures established the first target banking motion, while in runs against the simulated target, the initial rise in the oscillograph record of the programmed line-of-sight rate (fig. 7) signaled the target turn initiation. The end of the transition period, however, is not so evident and varies from run to run. Example time histories of errors during the period immediately following the target turn initiation are presented in figure 12. Examination of such time histories and rough calculations indicated that after about 7 seconds the quality of tracking was about the same as in the succeeding steady-turn tracking maneuver. Hence, the transition region was arbitrarily defined as the 7 seconds following turn initiation for purposes of analysis and comparison.

The average (or bias) and the standard deviation of the elevation and the azimuth tracking error were calculated for each phase of each selected gunnery run, all of which were left turns. The results for the transition region, averaged over a number of runs, are listed in table I. Standard deviations for the steady straight and steady turning phases, averaged over a number of runs, are plotted as a function of normal acceleration in figure 13. Over 70 standard gunnery runs were made against a simulated target and over 20 against an actual target airplane by various pilots. However, most of these data are not suitable for the present comparison because of differences in pilot experience in this program and small but possibly important changes in the target simulator and the test technique which occurred during the course of the development and evaluation program. The runs from which data are presented in the figure and table were limited to 12 runs against a simulated target and 6 runs against an actual target airplane by one experienced pilot. The data are thus not extensive, but care was used to insure consistent techniques and the data are considered representative.

DISCUSSION

Comparison of Tracking Characteristics Against an Actual and Simulated Target Airplane

The most apparent difference in measured tracking performance against actual and simulated target airplanes is the poorer tracking against a simulated target in the transition region. The data summarized in table I show that the bias errors against actual and simulated targets are small and about the same for the 2g turn and that the standard deviations are significantly greater for the simulated target. The data for the 3g turn show both large standard deviations and bias errors for the simulated target as compared to the values against the actual target airplane. These large errors against the simulated target can be explained qualitatively by reference to the example time history of figure 12. Against the actual target, the tracking pilot by observing the target banking motion is warned of the impending target turn and associated line-of-sight motion. As a result, no particular difficulty is experienced in tracking the target during the maneuver initiation; at least, the pilot is able to keep bias errors small and to hold the standard deviation to moderate levels during the transition. Against the simulated target, however, the tracking pilot receives no warning of the impending maneuver due to the lack of wings in the target display. As a result, the azimuth error builds up to sizable values before the tracking airplane makes the first corrective motion. At about 1-1/2 seconds, the attacking airplane starts to roll to the left; since the gun line is elevated above the airplane roll axis, this rolling motion tends to reduce the azimuth tracking error but tends to give an up elevation error as measured from coordinates fixed in the airplane. The large bias errors are associated primarily with this tracking deficiency during the intial portion of the transition. From about 2-1/2 until 4 seconds the attacker is turning at a rate somewhat greater than the line-of-sight rate in order to reduce both the elevation and azimuth error. From about 4 seconds on, oscillatory tracking errors occur as the tracking airplane settles down to the required steady turn. As indicated by the lower errors shown in table I for the 2g case, this tracking difficulty is a function of the magnitude and abruptness of the target turn. Unpublished flight tracking data from the NACA Langley Laboratory for different airplanes and test techniques indicate that the lack of target-bank information does not result in deterioration of tracking accuracy when line-of-sight motions are less abrupt than those employed in the present tests. In addition to maneuver abruptness, tracking performance in the transition region also is a function of the gun-line elevation (ref. 6), and of the tracking airplane dynamic and control characteristics (ref. 2).

In the steady straight and steady turning phases of the gunnery runs, bias errors were small (generally less than 3 mils), and the difference between the actual and simulated target values showed no consistent trend and were generally less than 1 mil. The standard deviations plotted in figure 13 for the actual target are generally low and show a small steady increase with normal acceleration. The values for the simulated target are about the same as for the actual target for steady straight flight, but are greater than the actual target case by about 1 mil in elevation and 2 mils in azimuth for steady turns. Several possible causes of this small but consistent difference were considered. There was a possibility that, compared to the situation for steady straight flight, the performance of the target simulator deteriorated in the more complex dynamic condition associated with the sizable line-of-sight commands and rolling motions in the turn maneuver. To check this, the simulated target azimuth line-of-sight motions in space were evaluated from GSAP movies of one run by measuring the motions of the gunsight and target dots relative to objects in the distant background. Although the results of this limited but tedious analysis cannot be considered conclusive, it appeared that the standard deviation of the difference between measured and desired target motions was less than 1 mil. This is consistent with the results of brief target-simulator space-stabilization checks, in which the airplane was oscillated about the various axes while in nominally straight flight. These runs showed that for an airplane oscillation of ±5 mils (the order of magnitude of tracking errors in the present tests) at a frequency of about 0.5 cps, the target dot oscillated about ±1 mil in yaw, and about ±0.7 mil in pitch. In the steady straight portions of the gunnery run, the tracking errors, and hence the unwanted dot motion due to airplane oscillations, were very small. This is reflected in the excellent agreement of the standard deviations for actual and simulated target shown in figure 13 for 1g flight. While small stabilization deficiencies account, in part, for the larger errors against the simulated target in the more perturbed turning flight condition, the project pilot commented on another possible cause of tracking difficulty. He noted that, although less important than in the transition phase, the lack of wings on the target dot resulted in some uncertainty as to the required bank angle in the steady turn. Apparently, the target wings ordinarily serve as a refined reference for observing and correcting small bank errors when the bank angle and motions with respect to the earth are large.

In general, the pilots felt that the problem of tracking the simulated target was a good representation of the problem of tracking an actual target which performs the maneuver selected for programming. The principal difference to them was the greater difficulty in tracking the simulated target during abrupt turn entries, due to the lack of target bank angle information discussed previously. The slight stabilization deficiency of the simulated target was noticeable to the pilots who felt that it might cause a small increase in random tracking errors, an opinion consistent with the results presented in figure 13. However, it did not seriously compromise their impression of tracking an actual target airplane. The solid target and fixed gunsight dots of different intensity and size were considered satisfactory after brief familiarization, but the use of a ring or other open-centered figure in place of one of the dots was recommended.

The data and experience gained in this flight-test program indicated that the optical target simulator would be a useful tool in tracking research. In addition to eliminating the need for a second airplane, the programming system provided accurate repetition of selected attacks. In the event that attacks involved abrupt target turn entries and associated high line-of-sight accelerations, the results indicated addition of target bank information to the display would be desirable. Although the stabilization characteristics were considered acceptable, improvement would also be desirable here for refined tracking research applications.[1] The tracking-error data were successfully recorded in time-history form, and clearly would be susceptible to rapid reading and analysis by various forms of automatic data-reduction devices. Even with the manual data-reduction methods used in the present study, the ease and convenience of using the oscillograph data in place of the GSAP movies was readily apparent.

Possible Extensions of Target Simulator Principles

Air-borne simulation is not restricted to the pure pursuit courses nor to the optical display associated with the prototype apparatus. Experience with this equipment has suggested a number of other possible devices based on similar principles. The complexity of the programming scheme and the information displayed to the pilot is of course dictated by the intended use of the device. For example, as mentioned in the Introduction, the design of a target simulator for use with radar-scope presentation is of interest. The fire-control system of concern here utilizes data from a self-tracking radar to compute a modified collision attack course, and the associated steering information is displayed to the pilot on the face of an oscilloscope. It appears that target simulators suitable for use with this equipment can be developed on the basis

[1]Substantial improvements in the stabilization properties of this line-of-sight reference system were obtained by relatively minor circuit changes made subsequently in another application of this equipment.

of experience with the prototype. However, the programming scheme using precomputed relative kinematics data may not be satisfactory in this case due to the comparative freedom allowed the pilot in making this type of attack and the consequent inability to predict the attacker motions. It might be more advisable to use the more generally applicable but more complex scheme such as diagrammed in figure 1. Here target motions are generated or programmed, attacker motions are measured by suitable instruments, and the data are sent to a relative kinematics computer which supplies the information normally derived from an actual target by the fire-control system. In addition to research uses, target simulators might prove useful in weapons-system evaluation and in pilot training.

Instead of representing a target airplane, as in the prototype simulator, the moving dot on the windscreen could be used to represent other external objects, for example, an air-launched rocket or missile. Since the dot is stabilized against own-ship motions but can be driven accurately in response to commands, the principal change in equipment would involve replacement of the target-kinematics programming system with a programmer and computer which would simulate the dynamic and kinematic properties of the missile of interest. In addition to research and development uses, such equipment might be applicable to pilot training.

The windscreen tracking display used in the target simulator can be thought of as forming a pitch and yaw attitude instrument. The moving target dot assumes a desired orientation specified by the program unit, while the fixed pip indicates the actual orientation of the gun line. Thus tracking errors can be interpreted as pitch and yaw errors. Since pilots were able to hold these attitude errors down to a few mils in various simulated target tracking runs, it appears that these programming and display principles might be applied fruitfully to certain instrument-flight problems. In this application, the larger dot would be an instrument index, programmed to correspond to a selected maneuver. The smaller dot would be a fixed index with which the pilot tracks the moving index in order to perform the selected maneuver. The feasibility of this scheme was indicated during the present program by brief flight tests in which precision constant-rate turns were programmed and successfully followed. Several features of such instrumentation may prove desirable. The windscreen display facilitates visual flight monitoring. The display is large and can be made very sensitive, and longitudinal and directional flight information can be combined in the tracking-problem form apparently readily handled by average pilots. In addition, the programming device accurately commands desired standard maneuvers.

CONCLUDING REMARKS

Flight investigation of the effects of various parameters on the tracking performance of fighter-type airplanes is an important but arduous task when conventional techniques are employed. The idea of an air-borne target simulator was recognized as a promising means of facilitating such research. The present investigation involved the design and flight evaluation of a prototype air-borne target simulator for use with optical gunsights, which was constructed primarily to demonstrate principles and furnish experience with problems of mechanization and operation of such equipment. In this simulator, a gyro-stabilized reference axis in the tracking airplane simulates the line of sight to a target airplane. The direction of this line of sight is reproduced optically by a dot on the windshield. To simulate a maneuvering target, the line-of-sight reference axis, and hence the target dot, is programmed to turn in the same manner as the line of sight to an actual target. The pilot tracks this moving target dot with the gunsight dot in the usual manner.

Quantitative data and pilots' comments were obtained from a brief flight evaluation which involved comparable fixed gunsight tracking runs on a simulated target and an actual target airplane. The standard maneuver which was used included periods of steady straight flight, steady turning flight, and the transition period associated with the abrupt target turn entry. Tracking errors in steady straight flight were nearly the same against actual and simulated targets, and were only 1 or 2 mils greater against the simulated target in steady turning flight. Tracking errors in the transition region (arbitrarily defined as the 7 seconds after target turn entry) were noticeably greater for the simulated target by an amount that increased with abruptness of the turn. This difference primarily was attributable to the lack of wings in the target dot and to the consequent loss of target bank angle information normally used by the tracking pilot to anticipate a target turn. Pilots' comments were in substantial agreement with the recorded data. They felt that the problem of tracking a simulated target was a good representation of the actual-target tracking problem. The most apparent difference was the greater difficulty in tracking the target dot during abrupt turn entries. Slight stabilization deficiencies of the simulated target led them to expect a slight increase in random tracking errors but did not seriously compromise their impression of tracking an actual target airplane.

The results of this evaluation indicate that the optical target simulator would be a useful tool in tracking research. In addition to eliminating the need for a second airplane, the programming system provided an accurate repetition of selected attacks. Addition of target bank information to the display and improvement of the stabilization properties of the simulated target might be desirable for certain tracking research applications. Tracking-error data were successfully recorded in time-history form susceptible to rapid analysis by various forms of automatic data-reduction devices as a replacement for the tedious conventional technique involving the frame by frame reading of movie film.

The experience with this prototype simulator suggested a number of other possible devices based on similar principles. These include a target simulator for use with fire-control systems involving a tracking radar and scope presentation, and an air-launched missile simulator. Of course, the method of programming and displaying the information to the pilot is dictated by the intended use of each device. In addition to research uses, these simulators might prove useful in weapons-system evaluation and in pilot training. Another application involves use of the windshield tracking display of the prototype simulator for a precision instrument flight display. This scheme offers several potential advantages over conventional forms of cockpit instrumentation.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., June 20, 1955

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TABLE I.- COMPARISON OF THE BIAS AND STANDARD DEVIATION OF TRACKING ERRORS AGAINST A SIMULATED AND AN ACTUAL TARGET AIRPLANE DURING TRANSITION INTO STEADY 2 AND 3g TURNS

Turn	Target	Standard deviation, mils		Bias error mils	
		σ_x	σ_y	$\bar{x}$ (1)	$\bar{y}$ (2)
3g	Simulated	13.0	10.8	8.55	8.67 U
	Actual	5.6	3.6	1.68	1.71 U
2g	Simulated	9.4	4.1	1.14	1.13 D
	Actual	5.4	2.9	3.82	2.00 D

[1]Target left of attacker fixed gunsight line.
[2]Target up (U) or down (D) relative to fixed gunsight line.

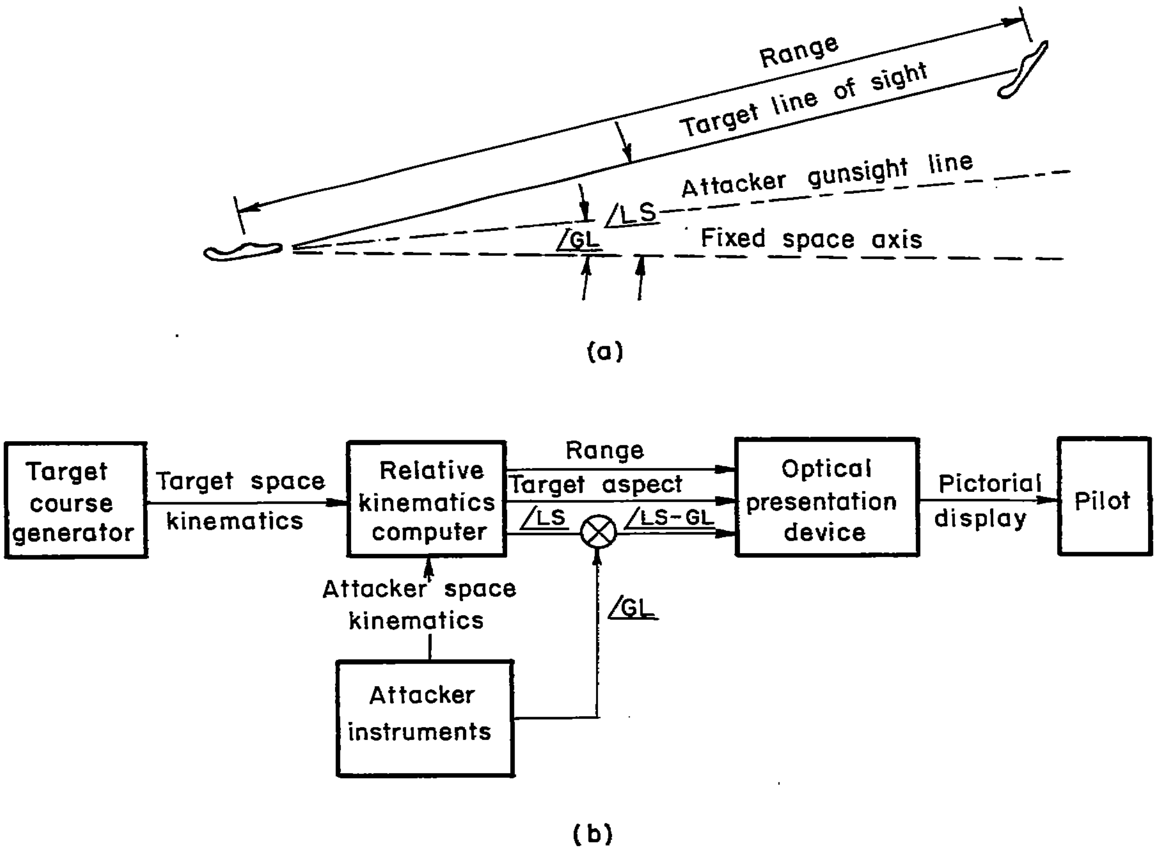
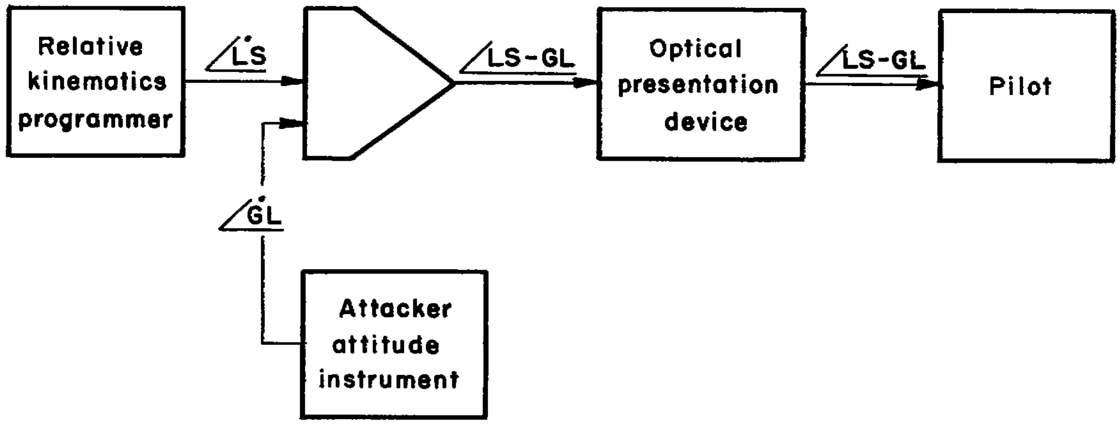
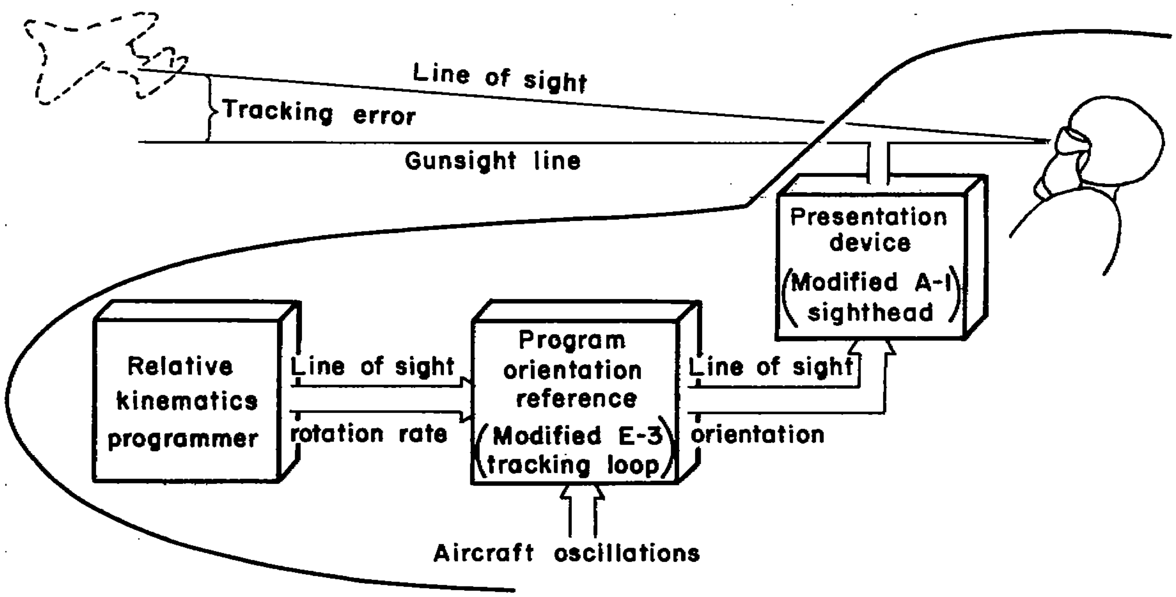


Figure 1.— Simplified diagrams of kinematic relations involved in an air-borne optical target simulator.



(a) Diagram showing simplifications obtained in an air-borne target simulator by programming relative kinematics data.



(b) Simplified diagram of the basic components of the prototype air-borne optical target simulator showing the use of a rate-commanded orientation reference.

Figure 2.— Simplified diagrams of air-borne target simulators using programmed relative kinematics data.

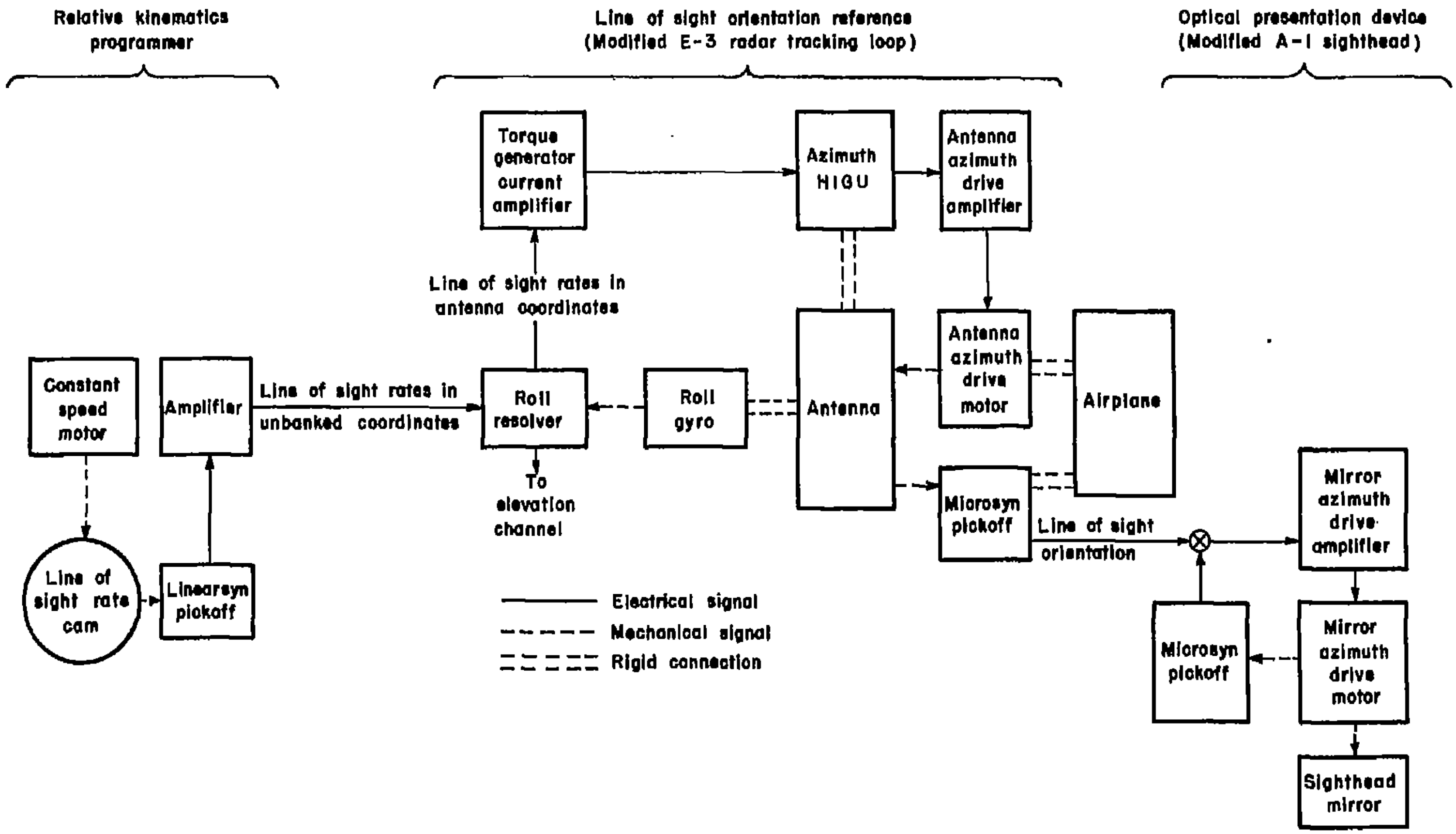
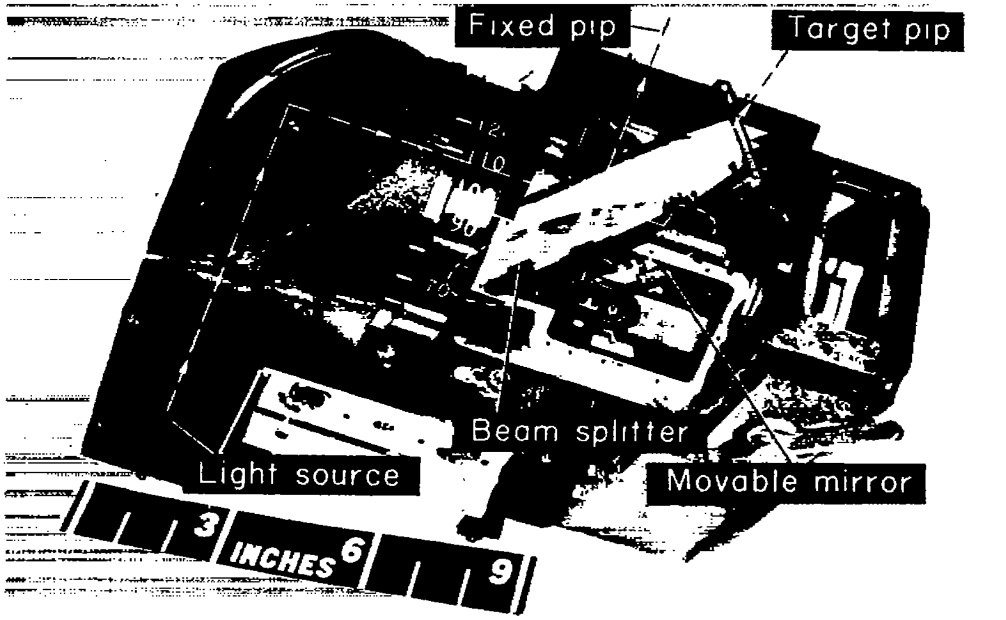


Figure 3.— Simplified diagram of azimuth channel of the prototype optical target simulator.



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(a) Modified A-1 sighthead with cover plates removed.

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(b) Optical target simulator components and GSAP camera installed in the cockpit of the test airplane.

Figure 4.- Cockpit components of the optical target simulator.

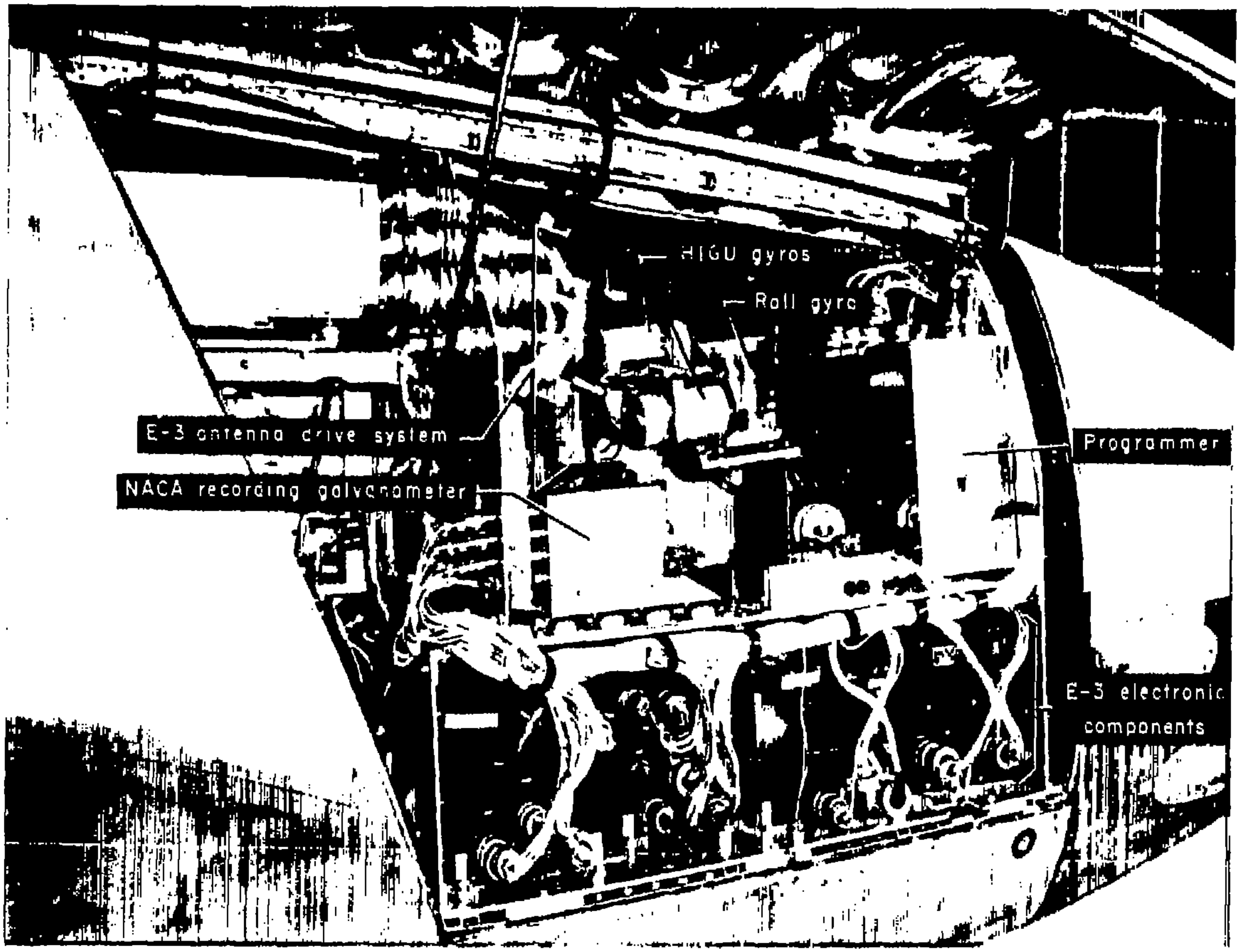

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Figure 5.- Optical target simulator components installed in nose compartment of test airplane.

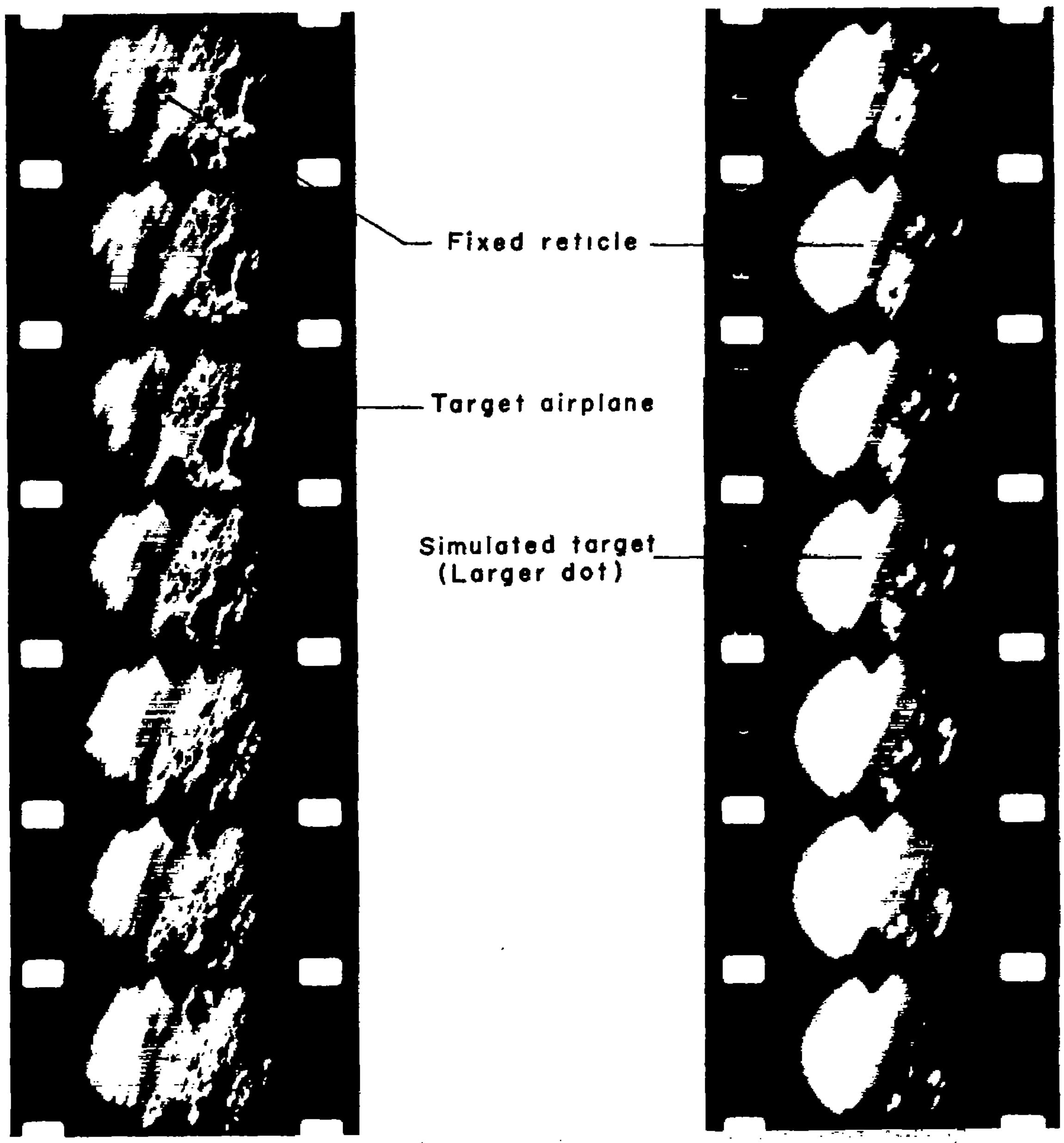


Figure 6.- Example gunsight-camera frames taken during steady-turn tracking against actual and simulated targets. Camera speed of seven frames per second.

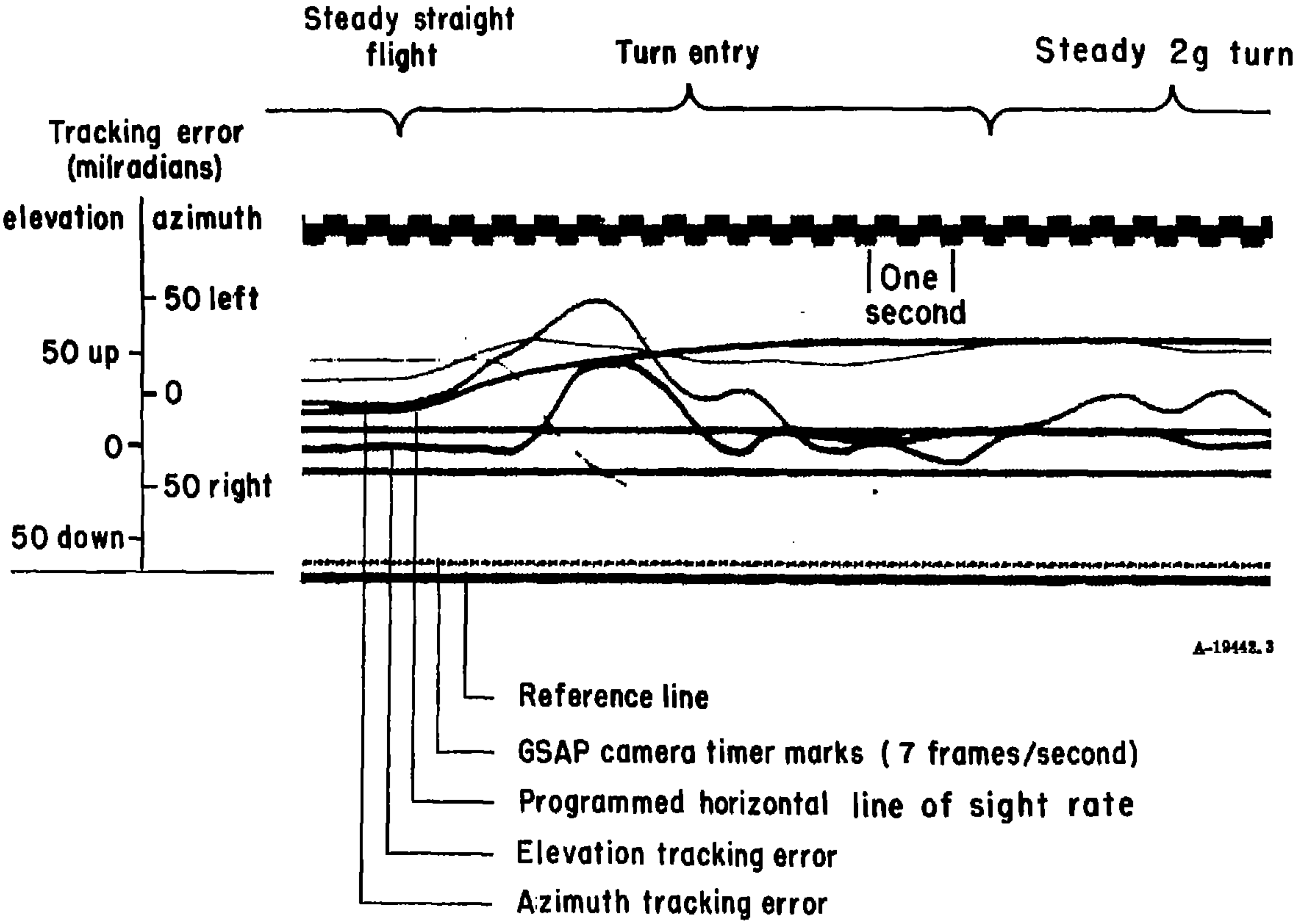
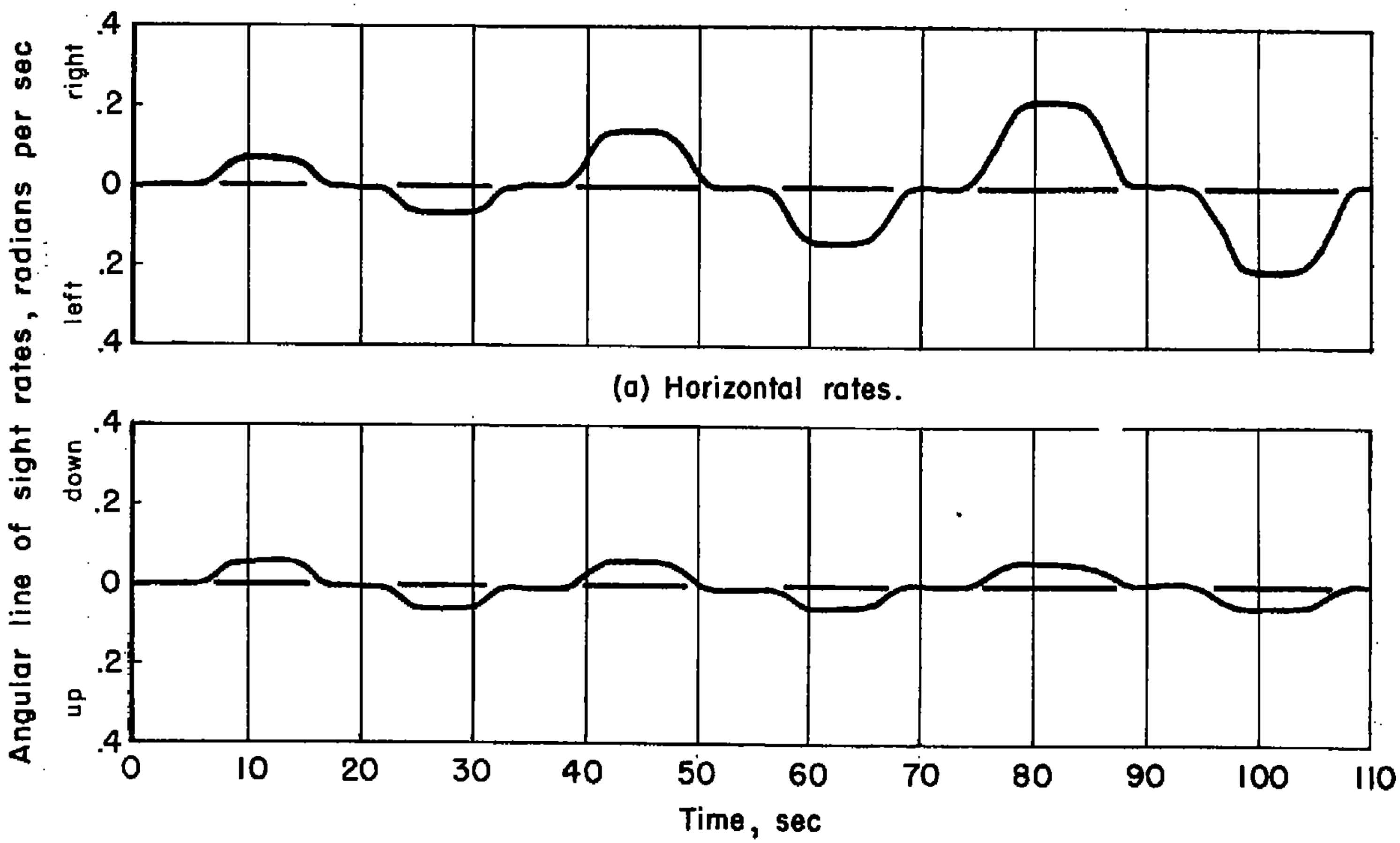


Figure 7.- Example color film from NACA oscillograph showing records from the transition portion of a simulated 2g maneuver.



(a) Horizontal rates.

(b) Vertical rates.

Figure 8.—Time histories of programmed maneuver rates for preliminary flight tests.

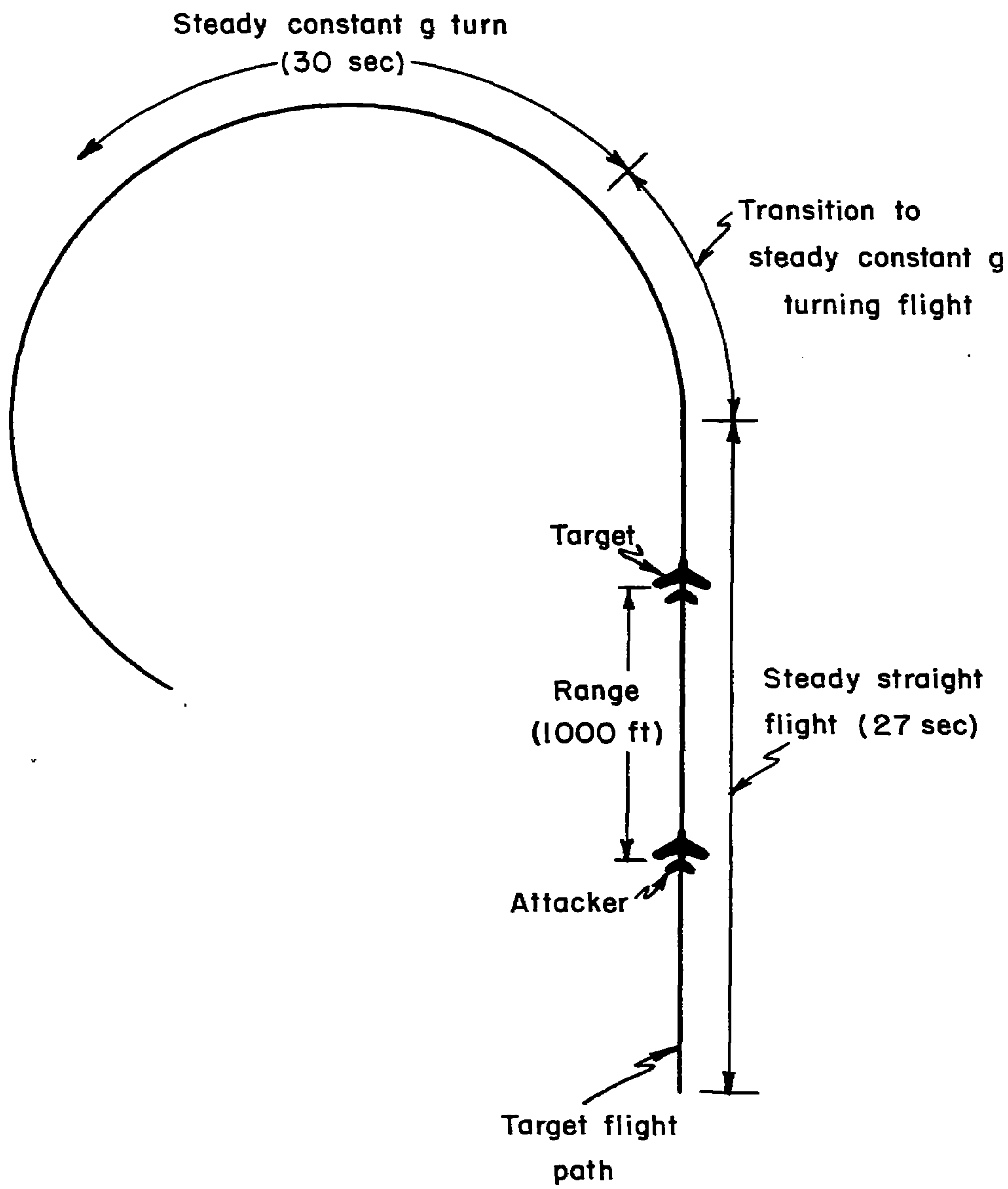
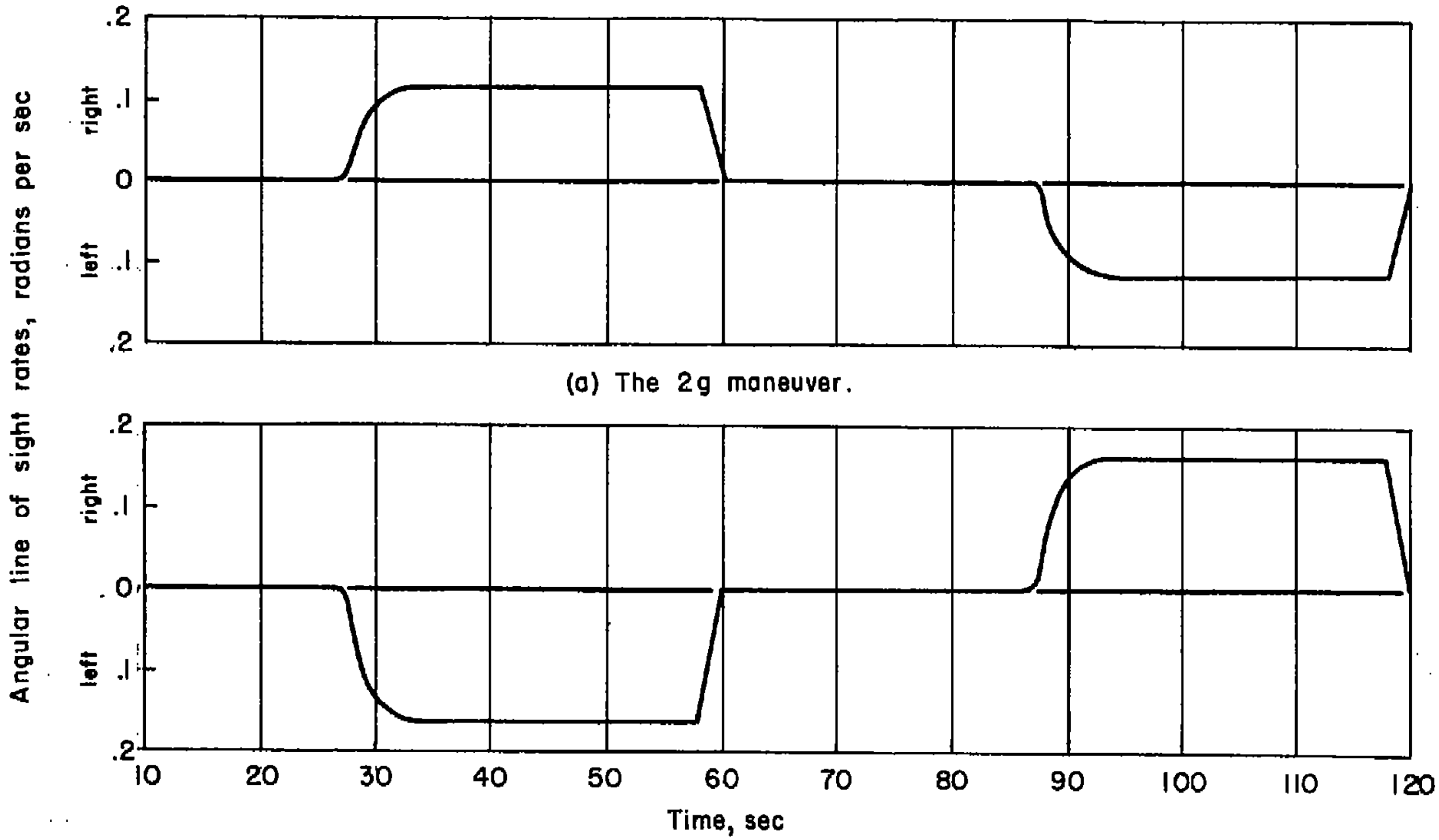


Figure 9.— Plan view of standard gunnery run used in tracking an actual and a simulated target airplane.



(a) The 2g maneuver.

(b) The 3g maneuver.

Figure 10.— Time histories of maneuver rates used in gunnery-run simulations.

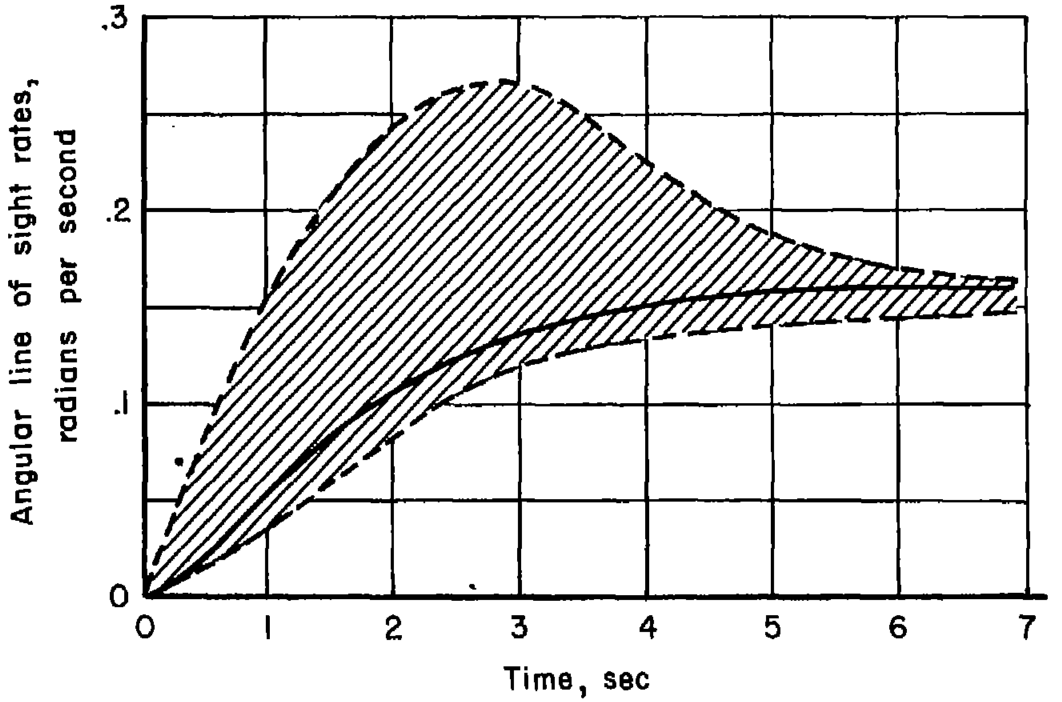
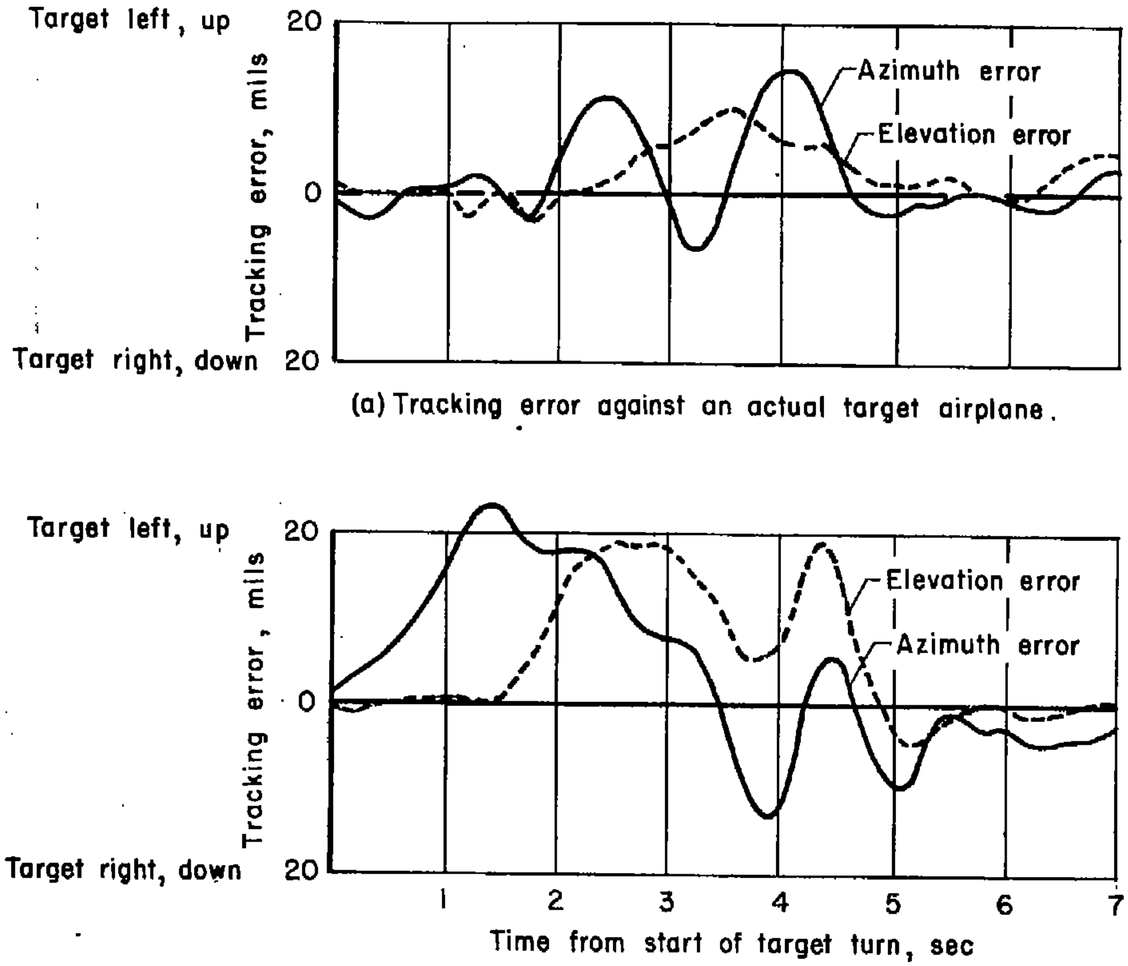


Figure 11.— Comparison of the rates computed for a 3g maneuver with the bounds of rates obtained in flights against an actual target.



(a) Tracking error against an actual target airplane.

(b) Tracking error against a simulated target airplane.

Figure 12.—Tracking error time histories from typical runs against an actual and a simulated target airplane during transition to steady 3g turns.

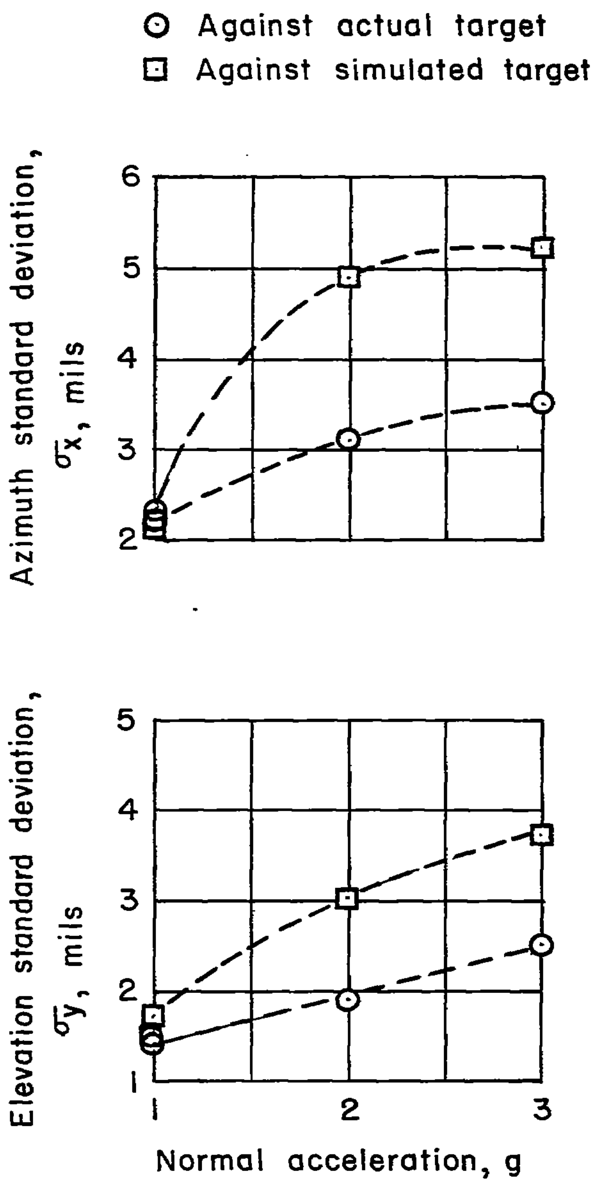


Figure 13.— Comparison of standard deviations of errors in tracking an actual and a simulated target.

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